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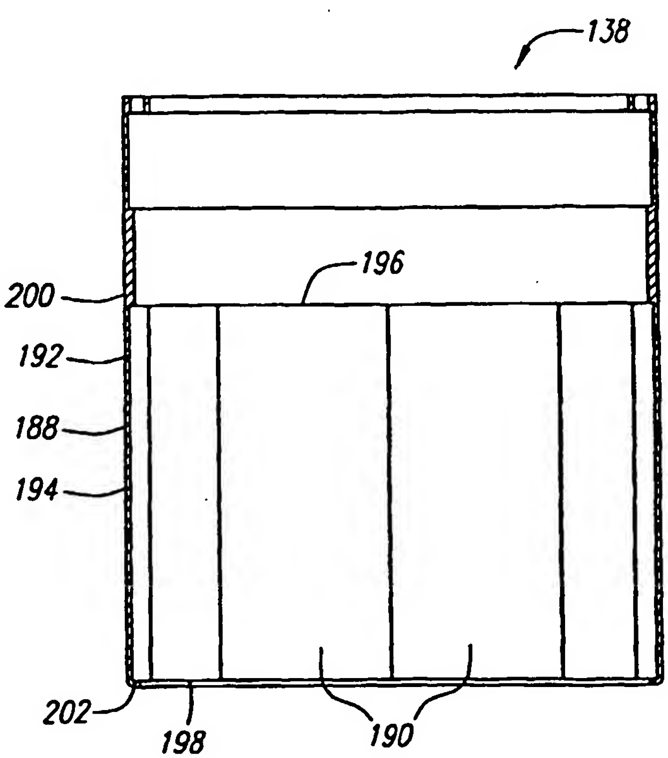
(54) Title: STIRLING CYCLE CTYOCOOLER WITH IMPROVED MAGNET RING ASSEMBLY AND GAS BEARINGS



(57) Abstract: A magnet ring assembly (138) for a piston/magnet assembly that can be used in a Stirling cycle cryocooler comprises a cylindrical magnet holder (188) and a plurality of magnet sectors (190) disposed on the inner surface of the magnet holder. The magnet sectors are captured in the rotational direction by bonding the magnet sectors to the inner surface of the magnet holder. The magnet sectors are also captured in the radial direction by providing them with a uniform radial magnetic field, such that they mutually repel each other against the inner surface of the magnet holder. Also, the edges of the magnet sectors are shaped, such any one magnet sector is prevented from being displaced radially inward by the edges of adjacent magnet sector. The magnet sectors are captured in the axial direction by forming an annular ledge (200) on the inner surface of the magnet holder on which one axial edge of each magnet sector rests, and swaging the axial edge(196, 198) of the magnet holder around the other axial edge of each magnet sector.

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SPECIFICATION

STIRLING CYCLE CRYOCOOLER WITH IMPROVED MAGNET RING ASSEMBLY AND GAS BEARINGS

Field of the Invention

The field of the invention relates generally to cryocoolers, and more particularly to Stirling cycle cryocoolers.

Background of the Invention

Recently, substantial attention has been directed to the field of superconductors and to systems and methods for using such products. Substantial attention also has been to directed to systems and methods for providing a cold environment (e.g., 77 K or lower) within which superconductor products such as superconducting filter systems may function.

One device that has been widely used to produce a cold environment within which superconductor devices may function is the Stirling cycle refrigeration unit or Stirling cycle cryocooler. Such devices typically comprise a displacer unit and a compressor unit, wherein the two units are in fluid communication and are driven by one or more linear or rotary motors. Conventional displacer units generally have a "cold" end and a "hot" end, the warm end being in fluid communication with the compressor unit. Displacer units generally include a displacer having a regenerator mounted therein for displacing a fluid, such as helium, from one end, i.e., the cold end of the displacer unit, to the other end, i.e., the warm end, of the displacer unit. A piston assembly of the motor functions to apply additional pressure to the fluid when the fluid is located substantially within the warm end of the displacer unit, and to relieve pressure from the fluid when the fluid is located substantially within the cold end of the displacer unit. In typical cryocoolers, the piston and displacer units oscillate at 60 Hz. In this fashion, the cold end of the displacer unit may be maintained, for example, at 77 K, while the warm end of the displacer unit is maintained, for example, at 15 degrees above ambient temperature. Devices such as superconducting filters are then typically placed in thermal contact with the cold end of the displacer unit via a heat acceptor. Heat is transferred from the device to the heat

Referring still to Fig. 2, the piston assembly 12 further comprises gas bearings 52 that receive gas, e.g., helium, from a sealed cavity 54 within the piston 40. It should be noted that any suitable of gas bearings 52 can be used. In the illustrated embodiment, four circumferentially disposed pairs of gas bearings 52 (only two pairs shown) are used. A check valve 56 (best shown in Fig. 1) provides a unidirectional flow of gas from the front of the piston 40, through the sealed cavity 54 and out through the gas bearings 52. Preferably, the gas bearings 52 comprise orifices that are on the order of a one or two mils (e.g., 1.5 mils), so that only a small amount of gas escapes from the sealed cavity 54 though the gas bearings 52, thereby preserving the pressure that has built up in the sealed cavity 54 until the next stroke of the piston 40. Typically, only 2-5 percent of gas that is displaced by the piston 40 enters the sealed cavity 54 through the check valve 56.

Because the smallest drill bit currently is around 2.9 mils with a maximum length of about 30 mils, the orifices of the gas bearings 52 cannot be drilled. Instead, each of the gas bearings 52 includes an aperture 58 in which there is disposed a gas bearing restrictor in the form of a screw 60 that can be turned to adjust the rate of gas that flows through the gas bearing 52. That is, the length of the passage created by the threaded helix between the screw 60 and the aperture 58 can be decreased or increased by carefully rotating the screw 60 in and out of the aperture 58 until the correct flow rates are attained in all gas bearings 52. Alternatively, sapphire/ruby or glass orifices (not shown) with very small diameters can be used as the gas bearing restrictor to provide a consistent gas flow at the designed rate without requiring adjustment. These orifices, however, can only be made so long, and as will be described in more detail below, have reliability problems. The piston assembly 12 further comprises centering ports 62 (shown in Fig. 1), which provide a return gas circuit from region adjacent the back of the piston 40 to the region adjacent the front of the piston 40.

Due to the tight tolerances (typically, about 5 mils) between the magnet ring assembly 14 and adjacent laminations (only internal lamination 28 shown) that are disposed on both the inside and outside surface of the magnet ring assembly 14, the circularity of the magnet ring assembly 14 must be perfect or near-perfect, so that it does not rub against the adjacent laminations. For the same reason, the concentricity between the piston 40 and the magnet ring assembly 14 must be perfect or near-perfect. In addition, the magnets 16 must be in a perfect or near-perfect cylindrical equidistant arrangement, so that the generated magnetic field is radially uniform. In this manner, a

between magnet and the magnet holder. It was also discovered that when sapphire/ruby or glass orifices are alternatively used as the gas restrictors, a static charge would build up as the gas flows through them at 60 Hz. As a result, very fine particles would collect within the very small diameters (typically about 0.0012 inch in diameter) and eventually plug them.

Thus, there is a need for an improved magnet ring assembly and gas bearing restrictor that can be used with piston assemblies, such as those found in cryocoolers.

Summary of the Invention

The present inventions are directed to magnet ring assemblies and piston/magnet assemblies, motors, and cryocoolers that utilize such magnet ring assemblies. In accordance with the present inventions, a magnet ring assembly comprises a cylindrical magnet holder having an inner surface, and one or more magnets disposed around the inner surface of the cylindrical magnet holder. In the preferred embodiment, a plurality of equidistantly spaced magnets is disposed around the inner surface of the cylindrical magnet holder. So that the magnets conform to the cylindrical magnet holder, each of the plurality of magnets is preferably arcuate and comprises an outer radius of curvature substantially equal to the inner radius of the cylindrical magnet holder. The magnets can be captured by the magnet holder in a variety of directions.

For example, the magnets can be rotationally captured by bonding them to the inner surface of the magnet holder. The magnets can be radially captured by providing the plurality of magnets with a radially uniform magnet polarity, such that they mutually magnetically repel each other against the inner surface of the cylindrical magnet holder. Also, each of the magnets can exhibit an outer arcuate length that is greater than the inner arcuate length, such that any one of the magnets is captured by the edges of the adjacent magnets, and thus cannot be displaced radially inward. The magnets can be axially captured by forming an annular ledge on the inner surface of the magnet holder and disposing one of the axial edges of each magnet on the annular ledge, and swaging the axial edge of magnet holder around the other axial edge of each of the magnets.

By way of non-limiting example, the afore-described magnet ring assembly provides various advantages. For example, the magnets can be mechanically captured to sustain high frequency operation of the piston on which the magnet ring assembly is mounted. Also, assuming that the magnet holder is a unibody structure, the number of

drawings depict only typical embodiments of the invention and are not therefore to be considered limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

Fig. 1 is a top view of a prior art piston/magnet assembly;

Fig. 2 is a cross-sectional view of the piston/magnet assembly of Fig. 1, taken along the line 2-2;

Fig. 3 is a perspective view of a magnet ring assembly used in the piston/magnet assembly of Fig. 1;

Fig. 4 is a top view of the magnet ring assembly of Fig. 3;

Fig. 5 is a cross-sectional view of the magnet ring assembly of Fig. 4, taken along the line 4-4;

Fig. 6 is a cross-sectional view of the magnet ring assembly of Fig. 4, taken along the line 5-5;

Fig. 7 is a cross-sectional view of a cryocooler constructed in accordance with one preferred embodiment of the present inventions;

Fig. 8 is a cross-sectional view of a novel piston/magnet assembly used in the cryocooler of Fig. 7;

Fig. 9 is another cross-sectional view of the piston/magnet assembly used in the cryocooler of Fig. 7;

Fig. 10 is still another cross-sectional view of the piston/magnet assembly used in the cryocooler of Fig. 7;

Fig. 11 is a close-up view of a novel gas bearing used in the piston/magnet assembly of Fig. 8;

Fig. 12 is a plan view of a composite tube used in the gas bearing of Fig. 11;

Fig. 13 is a perspective view of a novel magnet ring assembly used in the piston/magnet assembly of Fig. 8;

Fig. 14 is a cross-sectional view of the magnet ring assembly of Fig. 13, taken along the line 13-13; and

Fig. 15 is a cross-sectional view of the magnet ring assembly of Fig. 13, taken along the line 14-14.

that are circumferentially disposed about and circumferentially formed around the piston 142 in an equidistant manner, a substantially sealed cavity 156 formed within the piston 142 for providing gas, e.g., helium, to the gas bearings 154, and a check valve 158 that provides a unidirectional fluid communication conduit from the warm region P_{HOT} (i.e., the compression to chamber 114) to the sealed cavity 156 when the pressure of the gas within that region exceeds the pressure within the cavity 156 (i.e., exceeds the piston reservoir pressure). Thus, it can be appreciated that when the piston 142 moves towards the compression chamber 114, the gas from the compression chamber 114 is forced through the check valve 158, into the sealed cavity 156, and out through the gas bearings 154.

With specific reference to Fig. 11, the detailed structure of one of the gas bearings 154 will now be described. The gas bearing 154 comprises a bearing space 160 formed within the external surface 162 of the piston 142, an aperture 164 transversely extending from the bearing space 160 through the wall 164 of the piston 142 and into the sealed cavity 156, and a composite tube 166 that extends through the aperture 164. The composite tube 166 comprises a lumen 168 that is in communication between the bearing space 160 and the sealed cavity 156 to provide a flow of gas from the sealed cavity 156 into the cylinder 140.

Preferably, the aperture 164 is formed by transversely drilling a hole through wall 164 of the piston 142. In the illustrated embodiment, the hole has a diameter of approximately 0.020 inch and a length of 0.100 inch. The outer diameter and length of the composite tube 166 is approximately 0.020 inch and 0.100 inch, respectively, and the diameter of the lumen 168 is approximately 0.0012 inch. Thus, the relatively thick wall of the composite tube 166, which in the illustrated embodiment is approximately 0.0094 inch thick, allows the composite tube 166 to be easily press-fit into the aperture 164. Significantly, the composite tube 166 is composed of an electrically conductive material, such as, e.g., stainless steel. As a result, the composite tube 166 is electrically grounded through the electrically conductive piston 142, and thus, a "static charge" will not build up, thereby preventing or at least minimizing the collection of dust particles within the lumen 168. Also, because the diameter of the lumen 168 does not change during the manufacturing process of the cryocooler 100, and is consistent throughout any given run of a tubing, flow measurements for each gas bearing 154 need not be performed, or at the most performed only once, thus reducing cost.

on the inner surface of the cylinder 140, so that the rear space 178 momentarily communicates with the compression chamber 114 as the piston reciprocally moves within the cylinder 140, thereby equalizing the pressure between the rear space 178 and the compression chamber 114. Notably, the axial displacement between each of the double ports 180 or 184 provide a self-compensating air flow over an operating range of the piston 142. That is, only one port from each of the double ports 180 and 184 provide air flow during low piston 142 strokes, while both ports from each of the double ports 180 and 184 provide air flow during high piston 142 strokes. In this manner, the piston 142 is not axially biased towards the compression chamber 114 by pressure that may otherwise build up in the rear space 178 as gas flows from the gas bearings 154 into the rear space 178.

With specific reference to Figs. 13-15, the magnet ring assembly 138 will now be described. The magnet ring assembly 138 comprises a unibody cylindrical magnet holder 188 and a plurality of arcuate magnet sectors 190 mounted within the magnet holder 188. In the illustrated embodiment, eight magnet sectors 190 are used, but it should be understood, that any number of magnet sectors 190 can be used to provide the proper magnetic interaction with the magnetic induction assembly 134. The eight magnet sectors 190 are circumferentially disposed about the inner surface 192 of the magnet holder 188 in a circular equidistant pattern. Each of the magnet sectors 190 exhibits an outer radius of curvature r_l, and has an outer surface 191 within an outer arcuate length l_o and an inner surface 192 with an arcuate length l_l. So that the outer surfaces 191 of the magnet sectors 190 are flush within the inner surface 192 of the magnet holder 188, the outer radius of curvature r_l, for each of the magnet sectors 190 is equal to the inner radius r2 of the magnet holder 188.

The magnet holder 188 is composed of a high-resistivity material ($\geq$ 70 microhm cm), such as, e.g., stainless steel or any non-magnetic material. In this manner, magnetic losses through the magnet holder 188 are minimized. To further reduce the magnetic losses, the wall thickness of the magnet holder 188 surrounding the magnet sectors 190 is reduced, e.g., to less than 0.012 inch, by machining the outer surface 194 of the magnet holder 188. The inner surface 192 of the magnet holder 188 is machined to establish the true position to outer diameter needed for alignment of the piston 142 with the cylinder 140.

outer surface 194 of the magnet holder 188, the outer surface 194 can be grinded, such that it is concentric with the inner surface 192 thereof.

Referring back to Fig. 7, the magnetic induction assembly 134 comprises internal laminations 208 mounted to the outside of the cylinder 140, external laminations 210 that are mounted between the front and rear motor brackets 120 and 122 in close outward proximity to the magnet ring assembly 138 to form a gap (not shown), and a motor coil 212 that lies within the recesses formed within the external laminations 210 and surrounds the magnet ring assembly 138. The internal and external laminations 208 and 210 are preferably composed of a ferrous material. Thus, it will be appreciated that as the electrical polarity of the coil 212 is alternately switched back and forth, the resulting magnetic force that is applied to the magnet ring assembly 138 across the gap changes. As a result, the magnet ring assembly 138 reciprocally moves within the gap, and the piston 142 accordingly reciprocally moves within the cylinder 140.

The displacer unit 102 functions in a conventional manner and includes a displacer housing 214, a displacer cylinder assembly 216, a displacer rod 218, and a heat acceptor 220. The displacer cylinder assembly 216 comprises a displacer body 222 that is slideably mounted within the displacer housing 214, and a regenerator 224 mounted within the displacer body 222. The displacer body 222 rests against a displacer liner 226 affixed to an inner wall 228 of the displacer housing 214. The displacer rod 218 is slideably disposed within the displacer liner 152 mounted within the piston bore 150, and is coupled at one end 230 to a base section 231 of the displacer body 222 and coupled at the other end 232 to the displacer flexure spring 130. Thus, under appropriate conditions, it is possible for the displacer body 222 to oscillate within the displacer housing 214.

The heat acceptor 220 includes a radial component 234 and an annular component 236. The radial component 234 is generally perpendicular to the long axis of the displacer unit 102. The annular component 236 extends from the radial component 234 and extends axially beyond the edge of the displacer cylinder assembly 216, abutting against a distal end 238 of the displacer liner 226. The heat acceptor 220 is preferably brazed to the displacer housing 214 to provide a hermetically sealed environment. The heat acceptor 220 is preferably made from high purity copper or oxygen-free-high-conductivity (OFHC) copper. The displacer cylinder assembly 216 includes a plurality of radial holes 240. The radial holes 240 permits additional flow of helium within the cold region P_{COLD}, impinging directly on the heat acceptor 220. The radial holes 240 assist in decreasing the convective

through the displacer body 222, it deposits heat within the regenerator 224, and exits into the cold region P_{COLD} at approximately 77 K. At this time, the compressor piston 142 preferably is at mid-stroke and moving in the direction of the spring assembly 112. This causes the helium in the cold region P_{COLD} to expand further reducing the temperature of the helium and allowing the helium to absorb heat. In this fashion, the cold region P_{COLD} functions as a refrigeration unit and may act as a "cold" source.

Although particular embodiments of the present inventions have been shown and described, it will be understood that it is not intended to limit the present inventions to the preferred embodiments, and it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the present inventions. Thus, the present inventions are intended to cover alternatives, modifications, and equivalents, which may be included within the spirit and scope of the present inventions as defined by the claims.

11. The magnet ring assembly of claim 9, wherein each of the plurality of magnets exhibits an outer arcuate length and an inner arcuate length, the inner arcuate length being less than the outer arcuate length.

12. The magnet ring assembly of claim 7, wherein the plurality of magnets has a radially uniform magnetic polarity.

13. The magnet ring assembly of claim 6, wherein the one or more magnets is bonded to the inner surface of the cylindrical magnet holder.

14. The magnet ring assembly of claim 6, wherein the cylindrical magnet holder comprises an annular ledge formed around the inner surface of the cylindrical magnet holder, and each of the one or more magnets comprises opposing axial edges, one of the axial edges being disposed on the annular ledge.

15. The magnet ring assembly of claim 14, wherein the cylindrical magnet holder comprises a swaged axial edge opposite the annular ledge, and the other of the axial edges of each of the one or more magnets is captured by the swaged axial edge of the cylindrical magnet holder.

16. The magnet ring assembly of claim 6, wherein the cylindrical magnet holder is composed of a non-magnetic material.

17. The magnet ring assembly of claim 6, wherein the cylindrical magnet holder is a unibody structure.

18. A magnetic ring assembly for use with a piston assembly, comprising:

a plurality of magnets;

means for axially affixing the plurality of magnets;

means for rotationally affixing the plurality of magnets; and

means for radially affixing the plurality of magnets.

19. A motor, comprising:

a piston assembly including a cylinder, a piston that is reciprocally disposed within the cylinder, and a piston bracket disposed on the end of the piston;

a magnet ring assembly including a cylindrical magnet holder having an inner surface, and a plurality of magnets disposed around the inner surface of the cylindrical magnet holder, the magnet ring assembly being mounted to the piston bracket; and

a magnetic induction assembly operably coupled to the magnet ring assembly.

20. The motor of claim 19, wherein the magnets are equidistantly spaced from each other.

31. A cryocooler, comprising:

a compressor unit, including a piston assembly including a compressor cylinder, a compressor piston that is reciprocally disposed within the cylinder, and a piston bracket disposed on the end of the compressor piston;

a magnet ring assembly including a cylindrical magnet holder having an inner surface, and a plurality of magnets disposed around the inner surface of the cylindrical magnet holder, the magnet ring assembly being mounted to the piston bracket; and

a magnetic induction assembly operably coupled to the magnet ring assembly;

a displacer unit in fluid communication with the compressor unit; and

a heat exchange unit between the compressor unit and displacer unit.

32. The cryocooler of claim 31, wherein the magnets are equidistantly spaced from each other.

33. The cryocooler of claim 31, wherein each of the plurality of magnets is arcuate.

34. The cryocooler of claim 33, wherein the cylindrical magnet holder has an inner radius, and each of the plurality of magnets comprises an outer radius of curvature substantially equal to the inner radius of the cylindrical magnet holder.

35. The cryocooler of claim 33, wherein each of the plurality of magnets exhibits an outer arcuate length and an inner arcuate length, the inner arcuate length being less than the outer arcuate length.

36. The cryocooler of claim 31, wherein the plurality of magnets has a radially uniform magnetic polarity.

37. The cryocooler of claim 31, wherein the plurality of magnets is bonded to the inner surface of the cylindrical magnet holder.

38. The cryocooler of claim 31, wherein the cylindrical magnet holder comprises an annular ledge formed around the inner surface of the cylindrical magnet holder, and each of the plurality of magnets comprises opposing axial edges, one of the axial edges being disposed on the annular ledge.

39. The cryocooler of claim 31, wherein the cylindrical magnet holder comprises a swaged axial edge opposite the annular ledge, and the other of the axial edges of each of the plurality of magnets is captured by the swaged axial edge of the cylindrical magnet holder.

AMENDED CLAIMS

[Received by the International Bureau on 20 August 2003 (20.08.03): original claims 1-42 replaced by amended claims 1-38 (6 pages)]

1. A magnet ring assembly for use with a piston assembly, comprising:

a cylindrical magnet holder having an inner surface, an annular ledge formed around the inner surface of the cylindrical magnet holder, and a swaged axial edge opposite the annular ledge; and

a plurality of arcuate magnet sectors having a radially uniform magnetic polarity, the plurality of magnets being bonded around the inner surface of the cylindrical magnet holder, each of the plurality of magnets having opposing axial edges, one of the axial edges being disposed on the annular ledge, and the other of the axial edges being captured by the swaged axial edge of the cylindrical magnet holder.

2. The magnet ring assembly of claim 1, wherein the magnets are equidistantly spaced from each other.

3. The magnet ring assembly of claim 1, wherein the cylindrical magnet holder has an inner radius, and each of the plurality of magnets comprises an outer radius of curvature substantially equal to the inner radius of the cylindrical magnet holder.

4. The magnet ring assembly of claim 1, wherein the cylindrical magnet holder is composed of a non-magnetic material.

5. The magnet ring assembly of claim 1, wherein the cylindrical magnet holder is a unibody structure.

6. A magnet ring assembly for use with a piston assembly, comprising:

a cylindrical magnet holder having an inner surface and an annular ledge formed around the inner surface; and

15. The magnet ring assembly of claim 6, wherein the cylindrical magnet holder is composed of a non-magnetic material.

16. The magnet ring assembly of claim 6, wherein the cylindrical magnet holder is a unibody structure.

17. A motor, comprising:

a piston assembly including a cylinder, a piston that is reciprocally disposed within the cylinder, and a piston bracket disposed on the end of the piston;

a magnet ring assembly including a cylindrical magnet holder having an inner surface and an annular ledge formed around the inner surface, and a plurality of magnets disposed around the inner surface of the cylindrical magnet holder, each of the plurality of magnets comprising opposing axial edges, one of the axial edges being disposed on the annular ridge, the magnet ring assembly being mounted to the piston bracket; and

a magnetic induction assembly operably coupled to the magnet ring assembly.

18. The motor of claim 17, wherein the magnets are equidistantly spaced from each other.

19. The motor of claim 17, wherein each of the plurality of magnets is arcuate.

20. The motor of claim 19, wherein the cylindrical magnet holder has an inner radius, and each of the plurality of magnets comprises an outer radius of curvature substantially equal to the inner radius of the cylindrical magnet holder.

21. The motor of claim 19, wherein each of the plurality of magnets exhibits an outer arcuate length and an inner arcuate length, the inner arcuate length being less than the outer arcuate length.

a magnet ring assembly including a cylindrical magnet holder having an inner surface and an annular ledge formed around the inner surface, and a plurality of magnets disposed around the inner surface of the cylindrical magnet holder, each of the plurality of magnets comprising opposing axial edges, one of the axial edges being disposed on the annular ledge, the magnet ring assembly being mounted to the piston bracket; and

a magnetic induction assembly operably coupled to the magnet ring assembly;

a displacer unit in fluid communication with the compressor unit; and

a heat exchange unit between the compressor unit and displacer unit .

29. The cryocooler of claim 28, wherein the magnets are equidistantly spaced from each other.

30. The cryocooler of claim 28, wherein each of the plurality of magnets is arcuate.

31. The cryocooler of claim 30, wherein the cylindrical magnet holder has an inner radius, and each of the plurality of magnets comprises an outer radius of curvature substantially equal to the inner radius of the cylindrical magnet holder.

32. The cryocooler of claim 30, wherein each of the plurality of magnets exhibits an outer arcuate length and an inner arcuate length, the inner arcuate length being less than the outer arcuate length.

33. The cryocooler of claim 28, wherein the plurality of magnets has a radially uniform magnetic polarity.

34. The cryocooler of claim 28, wherein the plurality of magnets is bonded to the inner surface of the cylindrical magnet holder.

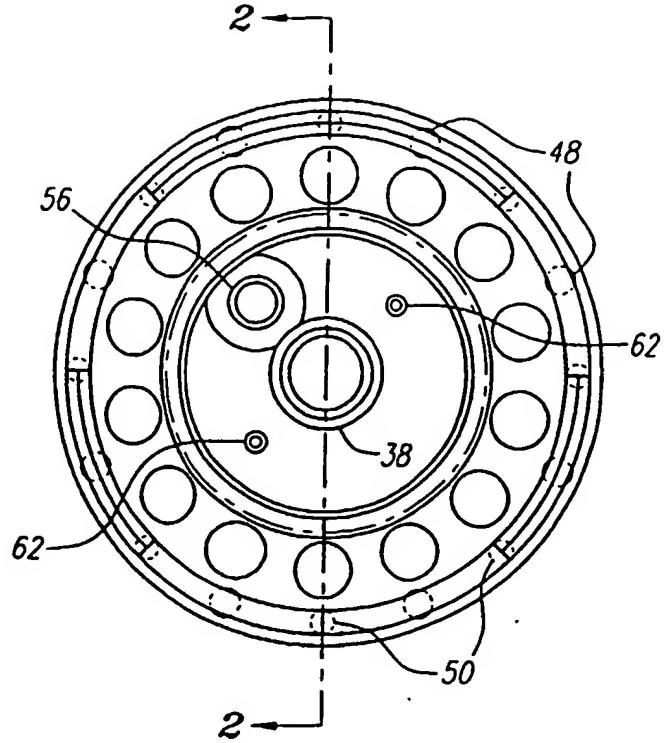
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FIG. 1

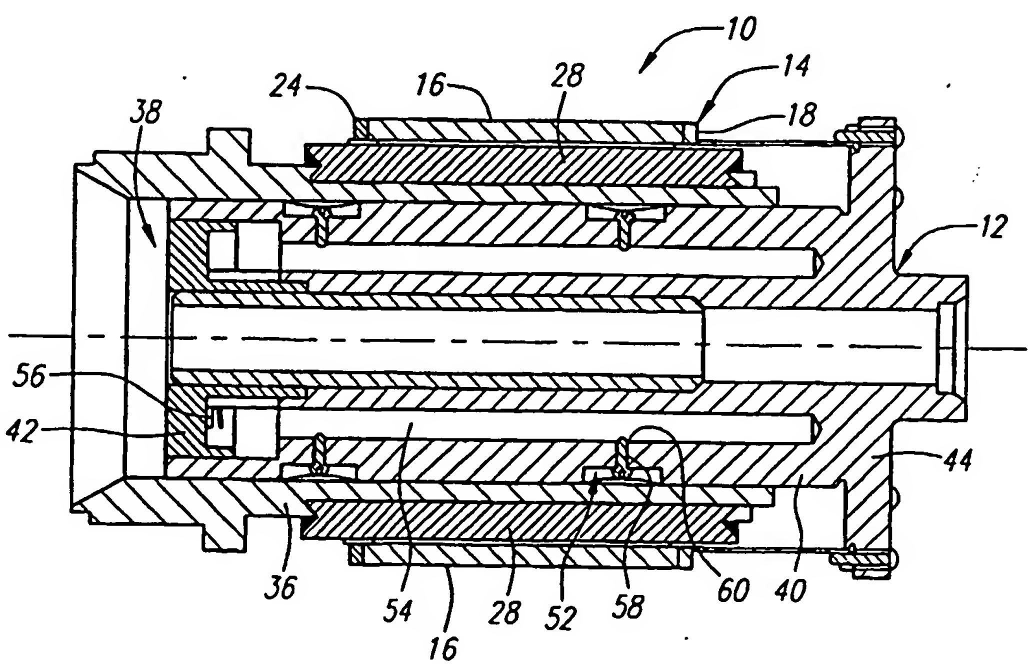
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FIG. 2

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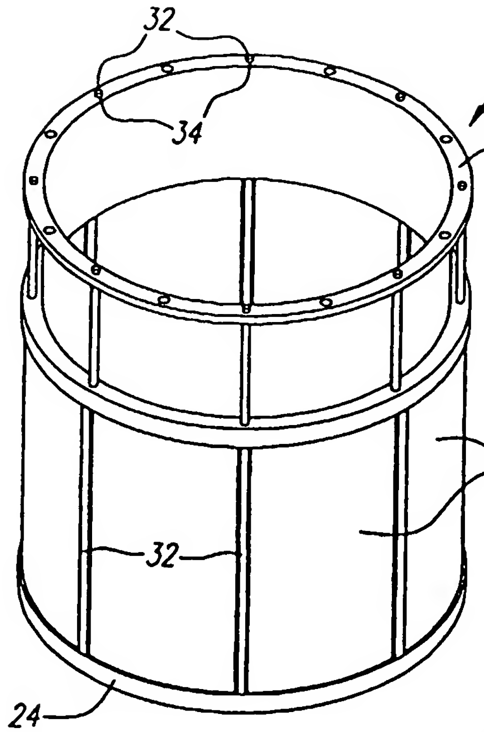


FIG. 3

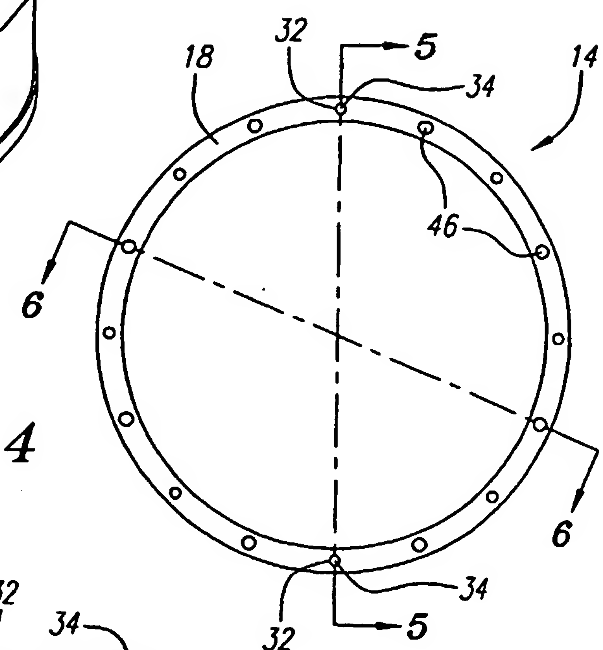


FIG. 4

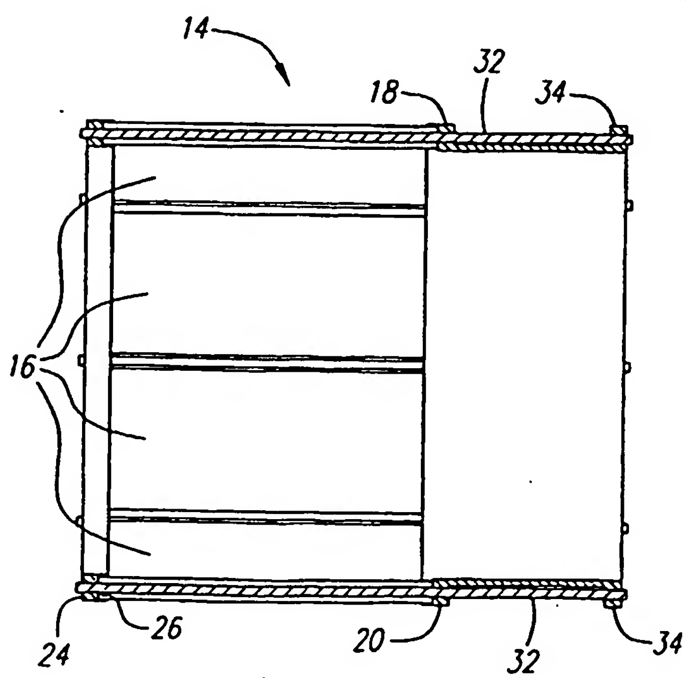


FIG. 5

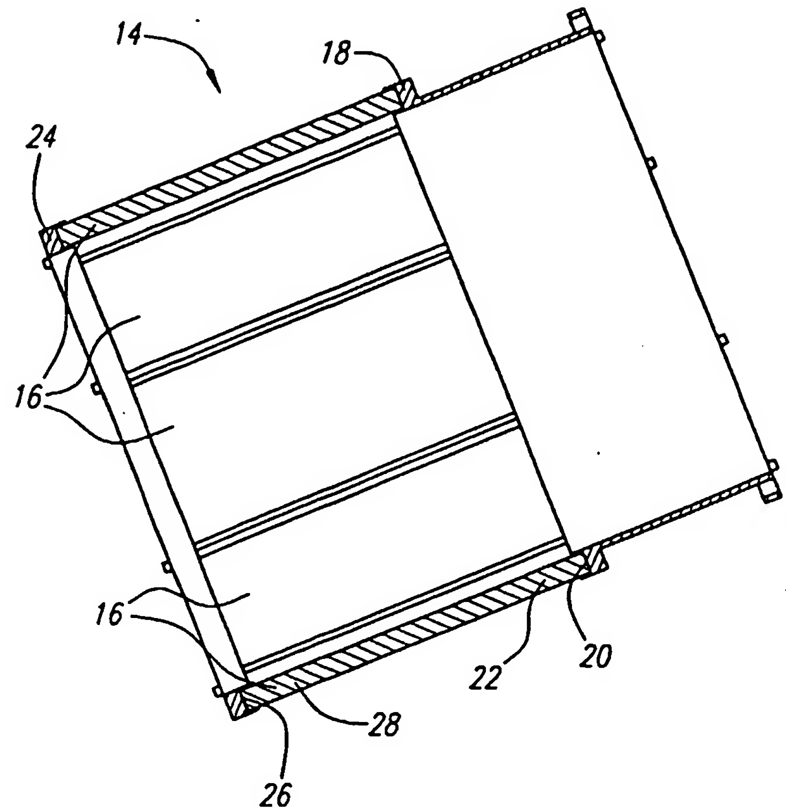
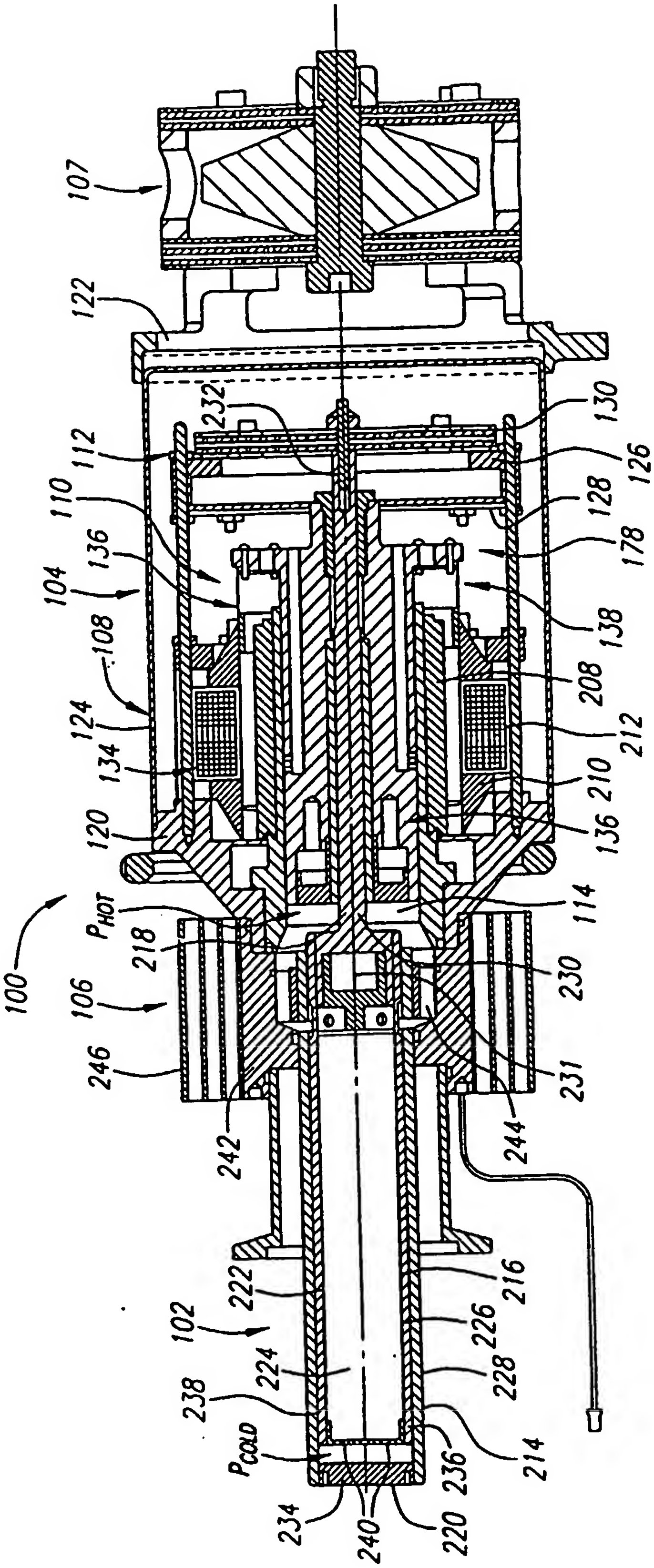


FIG. 6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P_{COLD}
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FIG. 7

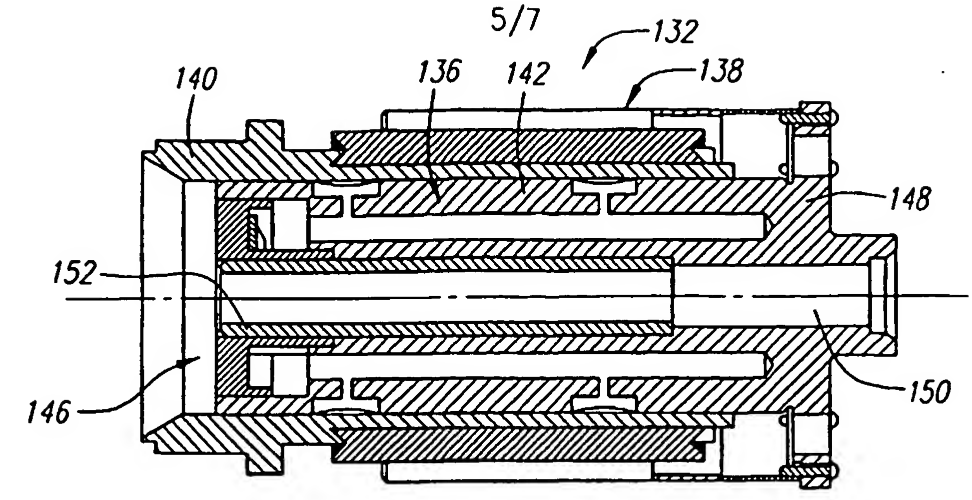

FIG. 8

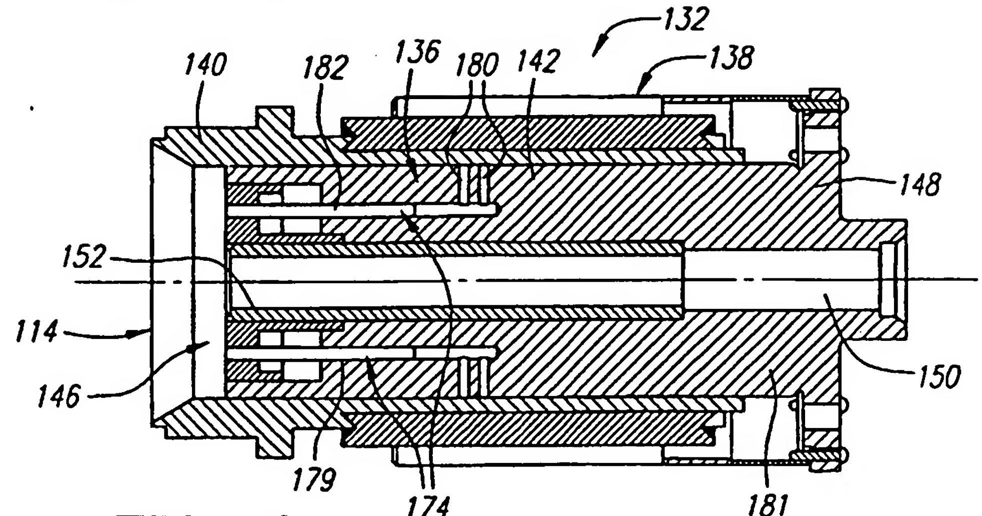

FIG. 9

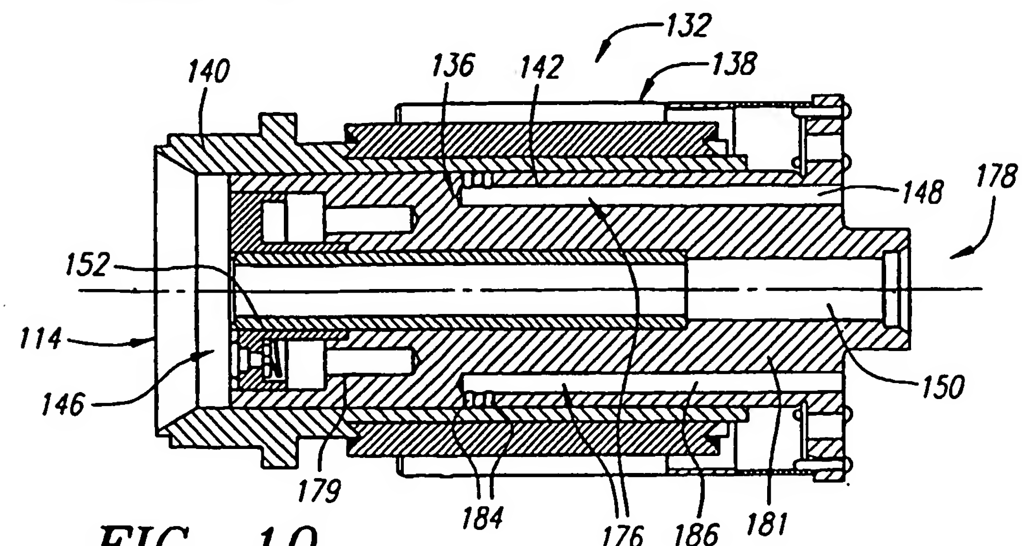

FIG. 10

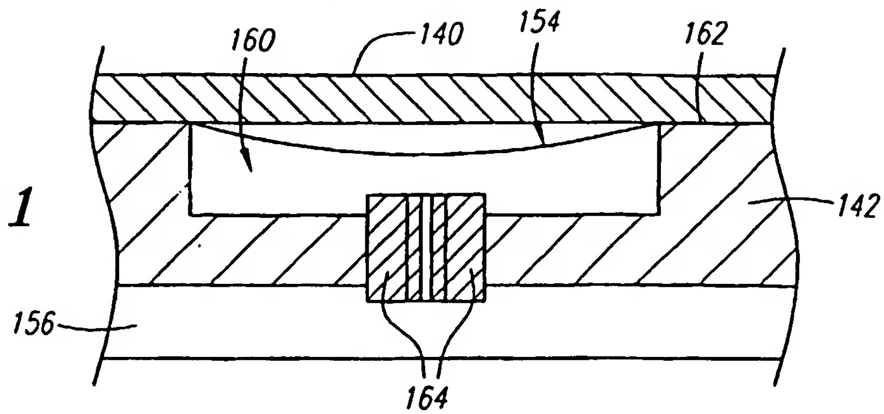

FIG. 11

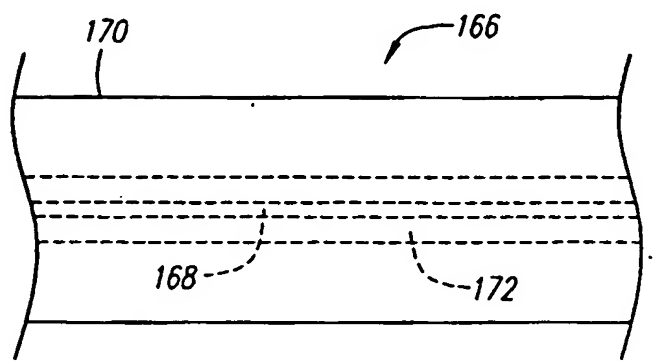

FIG. 12

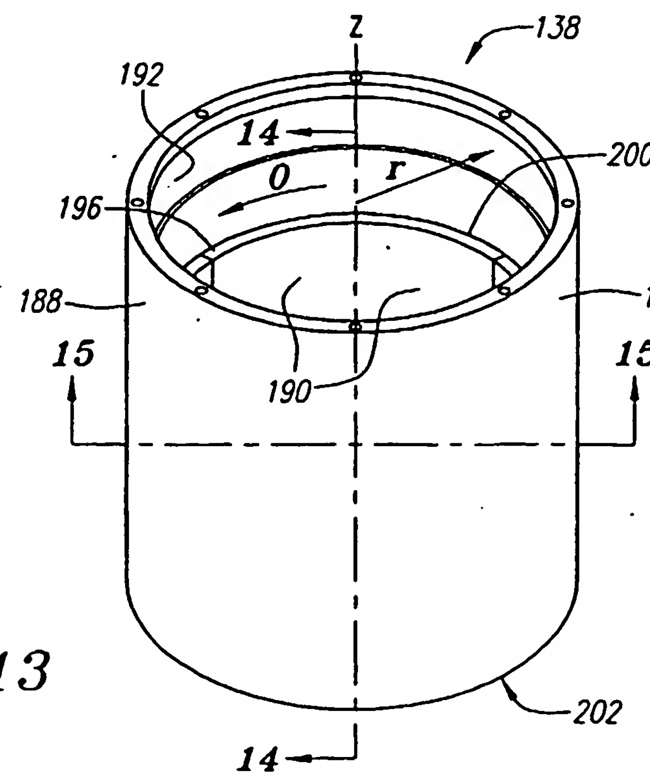

FIG. 13

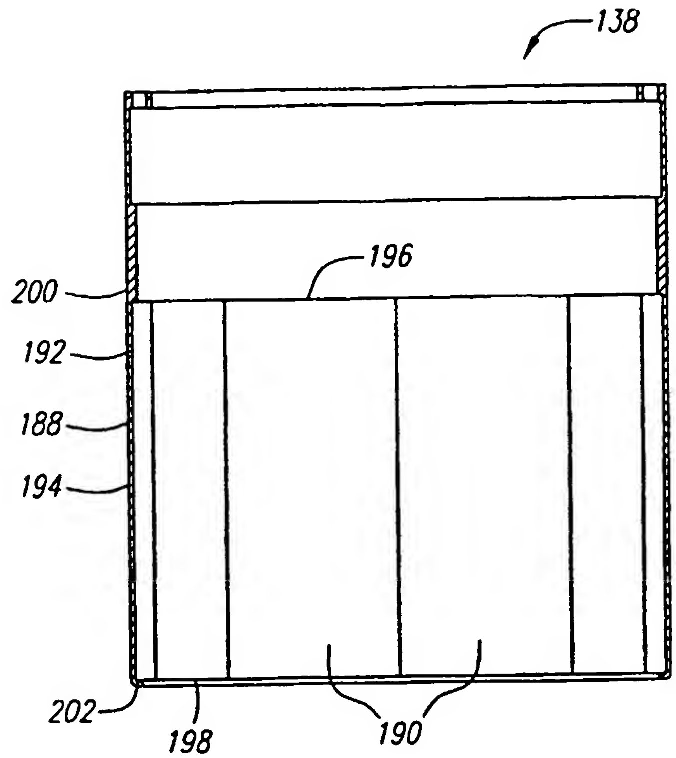
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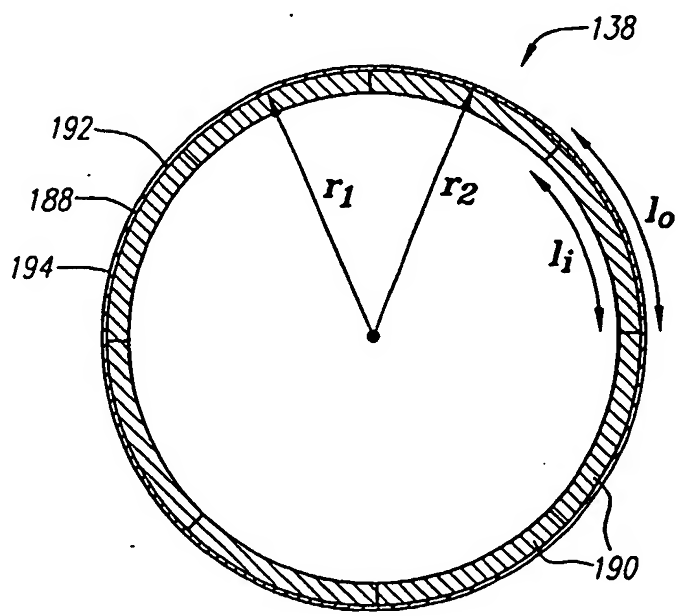
FIG. 14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r_1
r_2
l_o
l_i
190

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/14711

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : F01B 29/10
US CL : 60/517, 520, 524; 62/6
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 60/517, 520, 524; 62/6

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 4,987,329 A (SCHMIDT et al), 22 January 1991 (22.01.1991), see figure 1.	6-12, 16-18 ———— 13, 19-25, 28-29, 31-37, 40-41
X, P — Y	US 6,462,448 B1 (DU) 08 October 2002 (08.10.2002), see figure 1.	6-12, 16-18 ———— 13, 19-25, 28-29, 31-37, 40-41
Y	US 6,141,971 A (HANES) 07 November 2000 (07.11.2000), see figure 1.	19-25, 28-29, 31-37, 40-41
A	US 4,379,598 A (GOLDOWSKY) 12 April 1983 (12.04.1983), see figure 1.	1-42

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 July 2003 (23.07.2003)	07 AUG 2003
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703)305-3230	Authorized officer Hoang M Nguyen Diane Kinsale for Telephone No. (703) 308-0861